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NIGHT-SKY BRIGHTNESS IN BURKINA FASO: OUAGADOUGOU LIGHT POLLUTION ASSESSMENT AND IMPACT ON THE STARRY SKY OBSERVATION

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ABSTRACT

The quest for well-being and improvement of the populations living conditions in the borders of the big cities have changed habits in terms of lighting. The use of LED lamps and the reduction in the cost of photovoltaic panels, have allowed easy access to electricity nowadays. The lack of education on the nature of outdoor lighting has unfortunately led to an increase of light pollution.

This study uses VIIRS DNB Free Cloud Composites imagery to perform light pollution in Burkina Faso mainly in Ouagadougou, the main cities and surrounding areas. VIIRS imagery data obtained have been processed to get information of light pollution by classifying the information into several classes presented in a map.

Using VIIRS images, we show that light pollution has increased by 20% in Burkina Faso in major cities such Ouagadougou. Despite the fact that the illuminated surface per thousand inhabitants, ~0.09km^2, remains almost stable over the years. Areas of the city experience a decrease (<1%/year) in nighttime light while some areas have an explosion up to 50nW/cm^{2}sr a year due to the presence of new infrastructure.

Light pollution increases inside the city and the observation of the night sky becomes quite difficult in the inner city and still feasible on the outskirts of these cities.

KEYWORDS: Astronomy, Light Pollution, Dark sky, Ouagadougou.

1. INTRODUCTION

Light pollution has been a major concern for astronomers over those past years. Far from improving, light pollution is spreading to regions that were once spared. Burkina Faso is a country where the electrification rate is 38.6% in 2018 with an electrification urban rate of 68.69 % and less than 3.16 % in the rural area. The current policy is to increase this national rate to 60% by 2025. Despite this low coverage, some regions and cities had access to electricity for years from different sources. The presence and exploitation of light has increased since the establishment of a program and policy in favor of energy for all. Easy access to electricity and bad use of lighting can lead to light pollution.

Light pollution is the alteration of natural light levels in the outdoor environment owing to artificial light sources [1]. It is a global issue and affects most fields such as human sciences [2] , environment [3, 4] and astronomy [5]. From the global sky brightness map [6], some regions are extremely affected whereas other are relatively spared. This relative spareness is just a matter of time. In fact, urban expansion, poor lighting design and aerosols seems to be the biggest threat to light quietness [7]. To reduce or eliminate the negative effects of light pollution, studies have been conducted in several countries [6], [8], [9]. Those studies are necessary to limit the effects the artificial light pollution in main cities. In Burkina Faso however, in our knowledge no details study has ever being conducted.

(Cinzano et al. 2001) [1] shows that in Burkina Faso less than 7% of the population are living under a sky brightness greater than 0.11bn, with bn=8.61*107 Vphcm-2s-1sr-1. bn is a characteristic value which can be approximately compare to a visible magnitude of 21.6 in the V band magnitude per square arcsec.

Light pollution is noticed when the light measured is beyond the natural light; which is mainly from the solar radiation and affected by the location (the inclination of the solar rays and the impact of clouds). The natural intensity is also evaluated as 25 $\mu cd/m^2$ in [10].

Even though the country happens to be in the relatively light quiet zone, it is necessary to evaluate the evolution of the light brightness those last years in order to take appropriate preventive actions.

It is currently estimated that one fifth of the earth's surface is affected by the phenomenon of light pollution. This area would grow at a rate of 5-10% per year. The left map of the figure 1 shows that Burkina Faso is relatively a less light polluted country, however major cities such as Ouagadougou (see right panel of figure 1) happen to be highly polluted. This pollution is mainly due to the irradiation caused by the outdoor lighting.

Figure 1: Artificial night sky brightness for Burkina Faso. At left the map has been extracted From Light pollution info, colors are proportional to bn values. 0.11–0.33 (blue), 0.33–1 (green), 1–3 (yellow), 3–9 (orange) and 9–27 (red). The picture at the right is a EO image of Ouagadougou; it gives an idea of public lighting in the inner city.

2. MATERIALS AND METHODS

2.1 Lights levels measurement

Duriscoe et al. (2018) [11], not only describe the data reduction and also the impact of a light source on the pollution of a distant location but also show that light pollution measurement can be done through the Zenithal values (See [11] for a detailed description on Zenithal values). The brightness measures with azimuth angle ϕ, zenith angle z and $B_{\varphi,z}$ (μcd m^{-2}) as luminance is given by equation (1)

$$ZL = B_{\varphi,o} \qquad (1)$$

Using the reference condition of 171 μcd m^{-2} the zenith light pollution can be written as ZLR = ZLa / 171 where ZLa is the anthropogenic zenith luminance. The anthropogenic zenith luminance is corrected from the background natural light. Finally, the anthropogenic average sky luminance $ASLa$ is given by equation (2)

$$ASL_a = \frac{1}{2\pi}\int_0^{\pi/2}\int_0^{2\pi}(B - B_n)_{\varphi,z}\sin(z)dzd\varphi \qquad (2)$$

where *bn* is natural sky background brightness at φ, z. We can also use *250 μcd m* $^{-2}$ as the reference for the all-sky average then for all the sky, light pollution ratio becomes: ALR = ASLa / 250.

The sky brightness measured is generally a sum of natural sky brightness and the artificial sky brightness. The variation of the natural sky brightness is mostly from the solar activity and the artificial from human behavior. To determine the growth one uses the equation (3) same approach as in [12]

$$\frac{(b_{tot}-b_0)}{b_0} = \left(10^{-0.4(m_{tot}-m_0}\right) - 1 \qquad (3)$$

where m_0 is the natural sky brightness in the photometric band, b_0 the average natural sky brightness and b_{tot} the total sky brightness. The artificial brightness can be approximate as $(b_{tot} - b_0)$ once detections in the photometric bands are corrected form the extinction and air mass impact.

Taking into account the solar activities as suggested by [1], the magnitude per square arcsec m_{tot} of the total brightness in the V band can be well described by equation (4)

$$m_{tot} = -2.5log_{10}\left(\frac{b_{art}}{b_0} + \frac{b_{nat}}{b_0}\right) + m_0 \qquad (4)$$

The well-known nocturnal light at a specific site under specific environmental conditions remains limited when affected by clouds, snow [13]. But The growth of the pollution can be estimated by the ratio of the artificial light to the average natural light this variation with time is given in equation (5) adapted from [6] :

$$\frac{b_{art}}{b_0} = (RL)_{to}(1+p)^{t-to} \qquad (5)$$

where RL is the rate at the beginning year t_0, (typically 20 to 45%), p is the percentage of the annual growth rate and t the year.

2.2 Pollution Maps

We use raw and calibrated images from the Visible Infrared Imaging Radiometer Suite (VIIRS). VIIRS is an instrument on Suomi National Polar-Orbiting Partnership (Suomi NPP) spacecraft. VIIRS is used for environmental monitoring and weather forecasting. Its 22 imaging and radiometric bands cover wavelengths from 0.41 to 12.5 microns. The Day/Night Band (DNB), while operating in night mode observation is a useful tool to detect artificial pollution.

Before performing all kinds of dataset, the dark night brightness data is filtered to exclude data impacted by stray light, lightning, lunar illumination, and cloud-cover. Then the monthly and annual data are produced by averaging or summing observations on the location.

In general, the useful maps are cleaned from lights from aurora, fires, boats, and other temporal lights in order to avoid all types of discrepancies. For our location detections are free from aurora and boats but affected by bushfire during some periods of the year.

Data were taken from the catalog provided by Earth Observation Group, NOAA/NCEI and F. Falchi et al. (2016) [14], to perform the different curves. In this paper, Ouagadougou is the location of interest, hence its coordinates have been used as the centroids. The choice this location is linked to the ecological potential, to the frequentation or to the well-known lighting potential. Geographical Information System tools have been used to produce overlap maps and calculate the size of the irradiated area.

Bortle Dark-Sky Scale interpretation is another method use to evaluate the pollution in a location [15].
The Scale, in numerical nine-level allows the measurement of the night sky's brightness of a particular location. A location can be defined on the scale, from Class 1, the darkest skies available on Earth nice for astronomical observation to Class 9, usually the urban inner-city skies.

The Bortle class can be evaluated using the prevailing sky brightness, this value is the average magnitude of the two faintest bins marked as defined in equation (6):

$$C = [SB] = \frac{m_1 * t_1 + m_2 * t_2}{t_1 + t_2} \qquad (6)$$

where t is a tally and m is the fainter bracket magnitude that defines the magnitude interval bin.
Using the Bortle scale one can quantify the astronomical observability of celestial objects and the interference caused by light pollution.

3. EVOLUTION OF THE IRRADIANCE AND DISCUSSION

3.1 Global irradiance in Burkina Faso

The population of Burkina Faso is young and constantly growing. The population is now estimated to be around 20,900,000 (using INSD projections).

This growth is also followed by the extension of large cities such as Bobo Dioulasso and Ouagadougou, our study site. Government actions in the field of electrification and the increase in the standard of living of the populations make our cities more and more bright. From the analysis of the overall brightness, Burkina Faso is on an increasing slope but rather slow compared to the scale on a city or certain country in the North [12], [16], [17]. Indeed, data from VIIRS shows an increase in the gloss of over 24% between 2013 and 2018. As a whole Burkina presents 2.78∓0.31 Rad for a population of 1000 inhabitants this value has remained constant for years. This constant can be explained by the increase in the Burkinabé population, even though globally artificial radiation is becoming more and more disturbing in cities. In general, the country remains in a Bortle class lower than 4, which makes the country one of the best locations for astronomical observatories [18].

3.2 Light pollution in Ouagadougou

Like all the capitals of developing countries, the brightness of the night sky is on the rise in the Burkinabé capital, Ouagadougou. Figure 2 gives the evolution of the night sky brightness of Ouagadougou from 1992 to 2014. This figure reflects with a data number detection the impact of the evolution of the city on the quality of the sky.

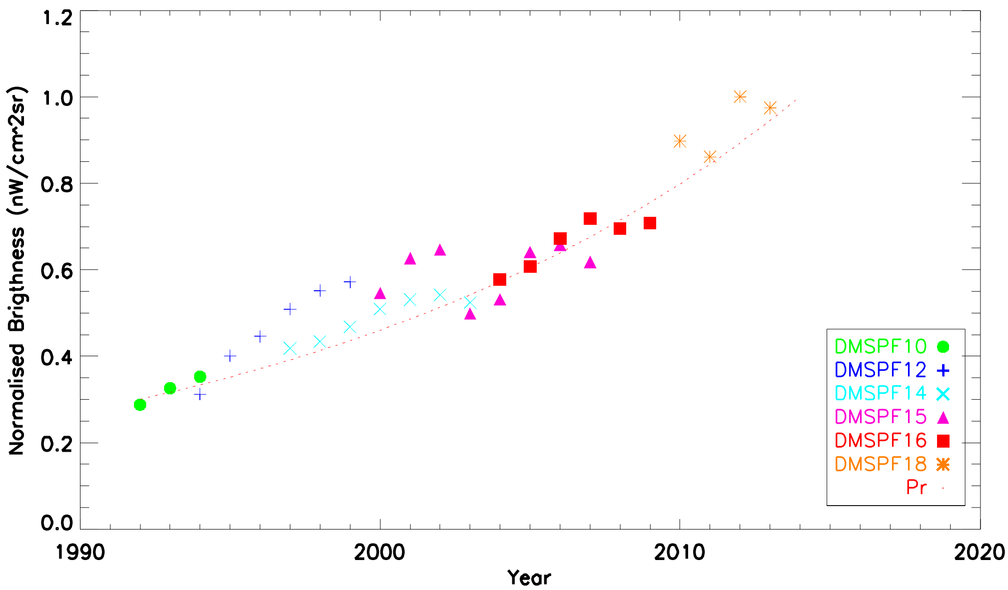

Figure 2 : Evolution of the summed radiance from Ouagadougou capital of Burkina Faso

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The dotted curve of the figure 2 gives the approximation of the mean evolution using equation 5 in model plotted with dotted line, p is 25% and represented the growth of pollution per year. The other colors represent the different type of detection over the years.

Indeed, the population of Ouagadougou has almost doubled in less than 7 years. This growth also generates an increase in the need for energy and a need for electrification. Figure 3 and the left panel of figure 4 show the evolution of the nocturnal illumination of the city of Ouagadougou from 2012 to 2019. We observe an increase in the irradiated surface from year to year with very strong areas of nocturnal illumination.

According to the projections on the evolution of the population of Ouagadougou year by year and the analysis of the surface covered by the nocturnal brightness, we have an area per 1000 inhabitants of ~0.07 km2 in 2012, ~0.1 km2 in 2013; 0.09 km2 in 2015 and ~0.09 km2 from 2015 to 2018. This shows that the city's surface polluted is increasing since the ratio remains almost constant.

If certain areas of the city are experiencing a reduction or stability in the sky brightness, the quality of the sky in other locations is severely degrading. Indeed, by observing around the Roundabout of United Nations (, 12°22'18 N, 1°31'11.W), we have an average irradiation we have an average irradiation of roughly 40.5∓6 nW/cm^2sr. The overall tendency is decreasing to reach a luminosity of the order of 29.7 nW/cm^2sr in April 2020. This roundabout is one of the nearest Point zero of Ouagadougou, it has a brightness of 2.17 mcd/m^2 an artificial brightness of 1990$\mu cd/m^2$ giving a ratio of about 11.7 and a Bortle Class 6. Even if we notice a brightness reduction in this place one can notice that it remains difficult from this place to count a significant number of stars.

Although the night brightness decreases in some areas of the city due to lamp change, other areas on the other hand, have a drastic increase of the night light. The peripheral zones are those which come first on the increase in night-time brightness. A typical case is the North interchange (figure 4, right panel), one can clearly see the bad effect of the road infrastructure on the night brightness. The interchange appears in the panel G of figure.3 as a red dot.

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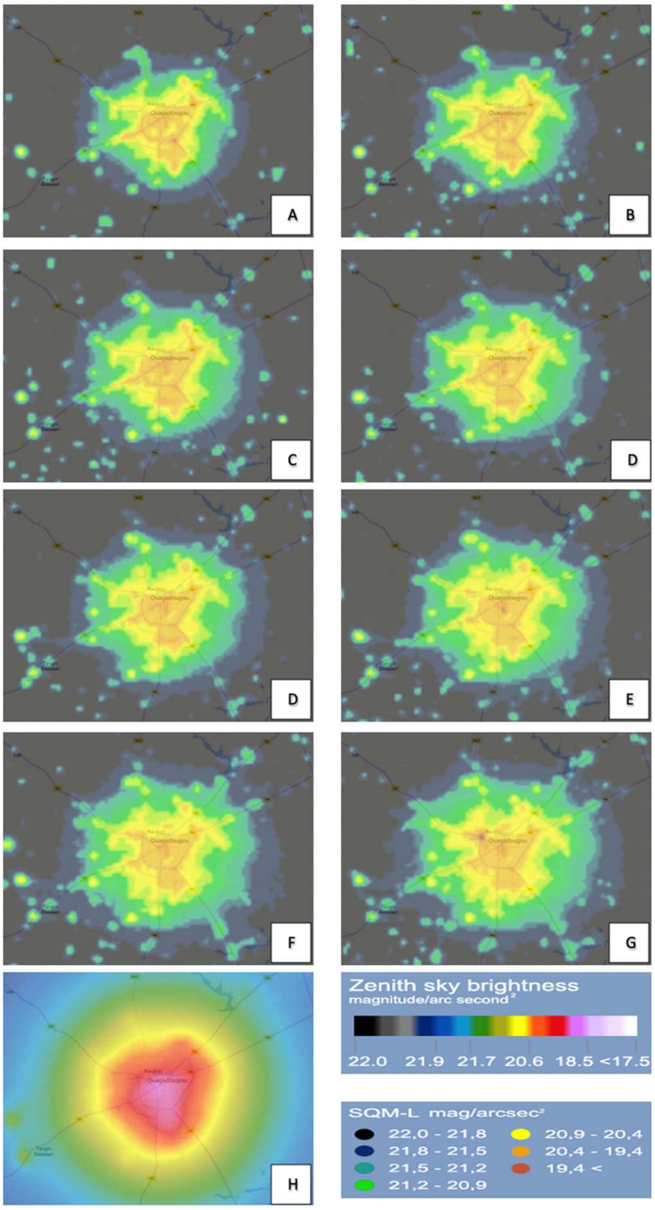

Figure 2 : Artificial night sky brightness for Ouagadougou. From top left to fourth line right image the sky brightness of Ouagadougou from 2012 to 2019. The bottom left is the Atlas 2015 night light and the bottom right images are the legend of Zenith sky bright

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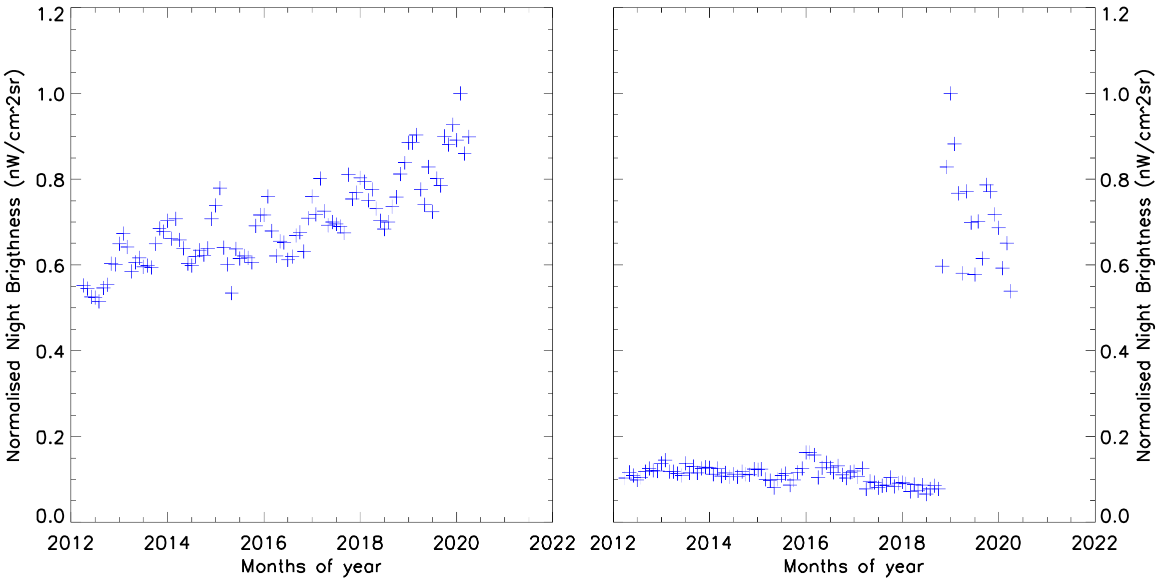

Figure 3 : Evolution of night brightness in Ouagadougou. The plot in left gives the normalized evolution around the centroid 1.5089 W, 12,3566N for ~1400 km2. The right plot shows the normalized irradiation at the North interchange.

3.3 Impact on astronomical observation.

The misuse of light, in terms of quantity and orientation, prevents stargazing. The first remark is the reduction in the number of stars observed with the naked eye. If the amount of artificial light produced in the dark night is not reduced, research in astrophysics and astronomy is greatly impacted (for example the closure of David Dunlop Observatory which was forced to close its doors because of the nightly brilliance of Toronto). Map H in Figure 3 shows strong irradiation of the regions in the center of the city of Ouagadougou, one of the causes is the poor orientation of the lamps, the type of lamp mainly due to a lack of regulations in the matter. Only the peripheral areas allow a good observation of the sky.

In the map H in figure 3, in the regions in magenta and red colors, deep sky observation is only possible in narrow wavelength bands (such as H alpha 6563 nm). The images taken are often affected by the low signal to noise ratio (S/N). In the orange and yellow regions, the use of broadband filters allows to obtain results with better S/N. Beyond these regions, observations are increasingly feasible with a more accessible deep sky. In the green regions and beyond Ouagadougou, long exposures are possible and extended objects and the deep sky accessible. In general, observations are affected

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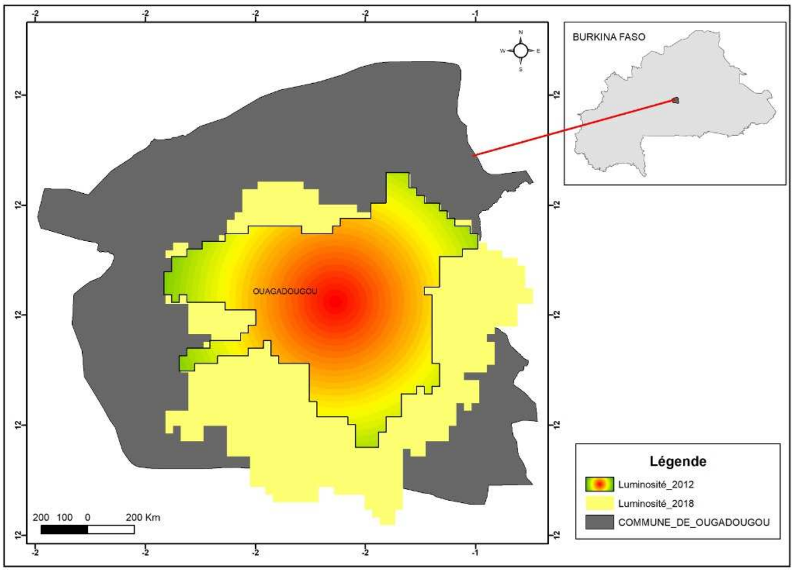

Figure 4 : Evolution of the upward radiance from nighttime operations at the Ouagadougou, capital of Burkina Faso, between 2012 and 2018. The gray surface gives the border of Ouagadougou performed by IGB. The yellow surface is detected by the Visible Infrared Image. The maps are represented in arbitrary color

The figure 5 also shows a superimposition of the irradiated regions of 2012 on that of 2018. This figure shows the orientation of the irradiation towards semi-urban areas and densely populated suburbs. Indeed, most of the nighttime lighting was in the city center and oriented outside towards the national RN1, but recent maps show more continuity in the rural communes of Saaba to the East, Loumbila to the North East and Tanguin Dassouri to the West.

Radiation in the city center is greater than 1.5nW/cm^2 sr. This part corresponds to the region inside the yellow crown of the map H. The magnitude of the irradiation evaluated in this zone is <20.9 mag/arcsec^2. Thus, all stars with a lower projected magnitude become problematic in terms of observation. From the center of Ouagadougou, on a diameter of 22.5∓0.7 km, the maximum quantity of visible stars is 550 ∓50 stars decreasing to reach a minimum of a hundred stars (for a radiation ~ 19.6mag/arcsec^2). Over an area of over 280 km^2, the Milky Way remains invisible to the naked eye. With each passing year the constellations familiar to early observational astronomy "disappear". The city of Ouagadougou is increasingly under the effect of light pollution and the pollution spreads gradually to the surrounding rural municipalities.

4. CONCLUSION AND FUTURE PROSPECTS

The study of the brightness of the night sky is a very important aspect for astronomy and for observing the sky and observing the earth from space. Several factors can affect the quantity of this observation, but human action contributes to reducing the quality of scientific data. In this study, we were able to highlight an increase in the DNB free cloud in the city of Ouagadougou, using the EO data from NOAA. At the same time, these data showed an enlargement of the illuminated surface ranging from single to double between 2012 and 2018. A surface that tends towards peripheral municipalities. This fact is linked to the constant expansion of the city but also to the availability of energy in peripheral areas following government programs. In fact, the neighboring rural communes are almost a continuation of the city of Ouagadougou following rural electrification and the drop in the costs of the components of autonomous photovoltaic installation and of mini photovoltaic power plant. This extension and availability of conventional and photovoltaic electricity supply unfortunately contributed to the reduction in the quality of the night sky and to poor knowledge of the starry sky by city dwellers. Only the brighter stars and planets are visible to the naked eye in the center of the city of Ouagadougou. Light pollution was a hindrance to the development of space science for health and the ecosystem, it is important to take measures for better management of lighting in terms of quantity and form. A better awareness of the action of man through light. We

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plant survey in the future with a Sky Quality Meter (SQM) to monitor the quality of lighting in urban and peri-urban areas of Burkina Faso. This study will also make it possible to advocate for better behavior in the field of public lighting.

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Conflicts of Interest
The authors declare no conflict of interest.

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